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Abstract
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Keywords: Colorado River water, Salton Sea, water scarcity, bankruptcy allocation, regional welfare, sectoral equity, social planner.

JEL Codes: Q25

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Introduction

With the realization of recent global trends in water scarcity and its future trajectory (Liu et al., 2017) it becomes harder to establish stable and sustainable water allocation schemes among users, both domestically (e.g., Stern and Pervaze 2019) and internationally (Dinar and Tsur 2017; Dinar and Dinar 2017; Dinar S. et al. 2015). This has been seen in regions where population growth leads to water conflicts with other water-intensive production sectors and with water-dependent environmental amenities.

Water allocation agreements among users sharing a common pool resource, such as water, under scarcity and supply variability introduce challenges to the regional economic performance and stability (Griffin, R.C. & Mjelde, J.W. 2000). This is likely to happen when such agreements are based on fixed quantities of the common pool resource, which are assigned as property rights to each of the users. In many regions of the world the amount of water in the shared common pool resource (river, groundwater aquifer) fluctuates over time and leads to significant deficits in the quantity that can be shared.

This was the situation, for example, in the case of the Ganges River basin at Farakkah, which is shared between India and Bangladesh. For quite some time the flow was subject to several fixed allocation agreements leading to disputes among the riparian states. It was not until the 1996 agreement that the allocation was based on proportions subject to the available amount at Farakkah at certain periods of the year. While the signatories to the agreement raise concerns about its bilateral benefits (Nishat and Faisal 2000), that agreement is still in effect and is supposed to be revisited after 30 years.

This is also the case in the Colorado River basin, which shares its water with seven states within the western U.S. and by Mexico through a compact among all riparians, using a fixed-allocation mechanism that was set at the level of flow in 1922. But due to the long-term reduction in the flow of water in the Colorado River, the 1922 compact fails to fulfil the agreed upon allocations of 16.46 million acre-feet (MAF) to the users, resulting in possible welfare losses and disputes (Figure 1).

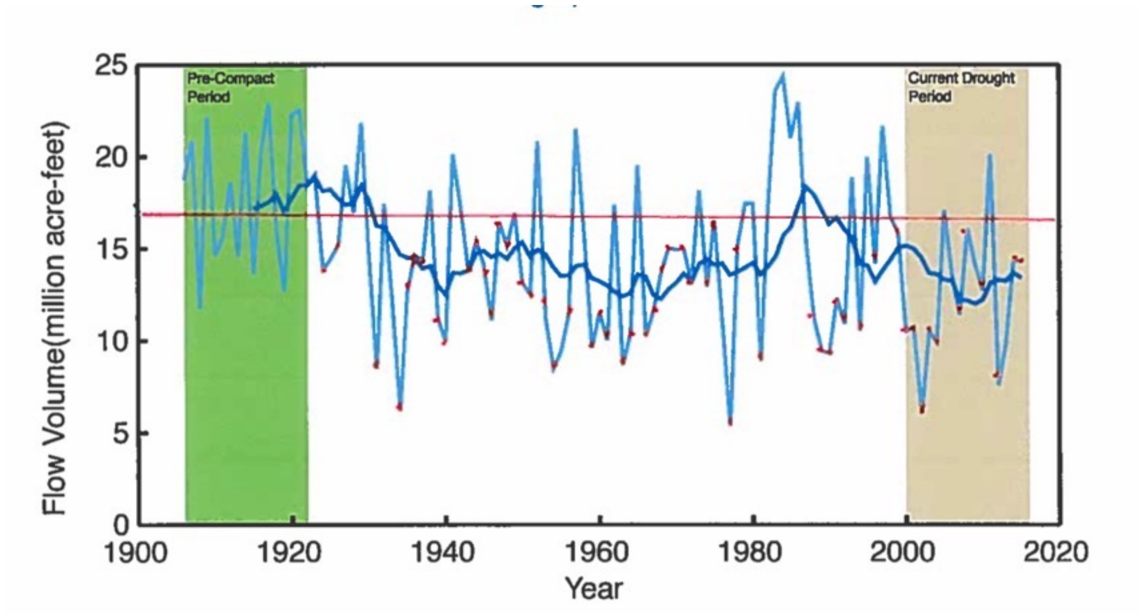


Figure 1: Natural water flow in the Colorado River 1906-2015.

Note: Light blue line marks the annual water flow; dark blue line marks the 10-year average flow; red line marks the 16.46 MAF in the 1922 compact.

Source: U.S. Department of the Interior (N.D).

As can be seen in Figure 1, between 1922 and 2015 river flow was lower than 16.46 MAF in 55 of the 92 years (nearly 60% of the years). Clearly, the claims of the riparians were not met in the past. As is expected (McCabe et al. 2017), occurrence of drought in the Colorado basin will increase due to climate change leading to an additional reduction in the flow and in the ability to allocate the agreed-upon quantities to the riparian states.

A situation in which a commitment of a common pool resource, such as water, to users cannot be fulfilled is defined as a bankruptcy. Generally speaking, a bankruptcy situation exists when agents submit claims that are larger than the available amount (either monetary or physical quantity), and that deficit has to be allocated among the claimants such that each will not receive a non-negative amount that cannot exceed the claim. Bankruptcy allocations rules have been developed for general situations (O'Neill, 1962; Aumann and Maschler, 1985; Branzei et al., 2008, to name a few).

Bankruptcy allocation rules were applied also to the water sector. Bankruptcy is relevant in the case of groundwater or reservoirs under scarcity situations, and even for international waters that are shared by several countries. Most, if not all, studies of which we are aware of applied bankruptcy allocation rules to hypothetical cases or simplified examples of actual cases (e.g., Madani and Dinar 2013; Shenlin et al. 2014; Mianabadi et al. 2014; Degefu and He 2016; Degefu et al. 2018), and legal principles of its application with examples (Klein 2012).

In this paper we focus on the Colorado water bankruptcy situation that affects Southern California and, in particular, the Salton Sea region. The paper seeks to address two issues that present themselves to the region surrounding the Salton Sea. The first issue being the shrinkage and resulting environmental degradation of the sea itself. The second issue is the lack of available water within the region to commit towards sustaining the sea and the economic activities of the communities.

Unlike previous studies, we refer in this paper to actual water demand and benefit functions of water-claiming entities, such as irrigation districts, urban utilities, and the Salton Sea itself. We develop a methodology to estimate water demand functions by consuming and producing sectors and the recreational value of water in the Salton Sea region. We apply a social planner approach to optimize the allocation of the deficit such that the regional welfare is maximized. We then apply a couple of bankruptcy allocation methods to calculate the resulting sectoral and regional welfare, and compare the total regional welfare and the sectoral distribution of the welfare between the social planner and the bankruptcy allocations.

Within the wider context of research concerning management of scarce water resources, this paper adds to the literature by developing an allocation framework that includes both the urban and agricultural sectors as equal stakeholders, as opposed to focusing on allocating within one sector or region in the existing literature. Within the context of managing Colorado River water supplies in the Salton Sea region, the paper contributes by deviating from traditional market-based methods of managing water scarcity by simulating the imposition of a bankruptcy allocation framework.

The paper continues with a description of the region, followed by an overview of the methodology used to derive the estimated water demand functions of urban use, agricultural use, and the economic benefits of the sea itself across all stakeholders. This methodology also includes an outline of the means by which we reallocate water from the Colorado River. Then we move on to a more in-depth look at the empirical application of our methods, which involves providing greater detail of the quantitative basis for our demand functions. We also explain the different ways in which a demand function can be applied to different sectors and the data limitations as they pertain to individual stakeholders. The empirical application of the bankruptcy allocation involves the simulations of three water delivery systems, and descriptions of the impacts these have on the various sectors and stakeholders. We then present and discuss the resulting application systems as well as the implications our proposed allocation system would have on future policies.

The Salton Sea Study Area

The Salton Sea is situated in the Colorado Desert (Appendix Figure 1), a region at the far southwest of the state of California. It is part of an ephemeral lakebed that has flooded and evaporated intermittently for thousands of years. In 1905, a diversion of the Colorado River water for large-scale agricultural irrigation was attempted, but technical failures resulted in the entire Colorado River changing course and flowing into the Salton Sink. This breach was impossible to fix until 1907, which meant that the river had flowed uninterrupted for two years into the lakebed, thus creating the most recent incarnation of the Salton Sea. Over the last century the sea was maintained through agricultural inflows and regular diversions of water to the sea to satisfy various economic functions and environmental concerns. Yet in recent decades inflows into the Salton Sea have been reducing and the expiration of a quantification settlement agreement which guaranteed between 15,000 to 150,000 acre-feet per year for the Salton Sea has jeopardized the long-term sustainability of the sea (United States Congress 2003; QSA Annual Report 2015).

Over the past century more than 90 of the 4 million acres of wetlands within the state of California have disappeared due to encroachment by urban areas, drainage for use as farmland, and water sources being requisitioned for agriculture. These wetlands served as a habitat for millions of migratory birds flying along the Pacific Flyway, which were put under increasing strain due to the shrinking wetlands area (United States Geological Survey 2007; Central Valley Joint Venture 2003). When the Salton Sea formed, its conditions became similar to those of the old wetlands, which resulted in wildlife adopting the Salton Sea as a surrogate habitat (Cohen, et al. 1999). To date, what was once an irrigation mishap is home to over 380 species of birds, including six species that are federally protected. Some of these species inhabit the area as a stop on a larger migration path, and others are present on a more permanent basis.

The deterioration of the Salton Sea also creates a significant health hazard to the population in the surrounding region due to the air pollution it produces. Because the sea is fed by agricultural runoff it has been contaminated by various hazardous chemicals, most significantly silica. When the water level drops it leaves these materials on the lakebed as particulate matter which can be carried by the wind and inhaled by residents in the surrounding region (Ostro, et al. 1999).

Furthermore, the region surrounding the Salton Sea, particularly the Coachella Valley, relies on tourism as an economic engine. A report produced for the Greater Palm Springs Convention & Visitors Bureau (GPSCVB) by *Tourism Economics*, indicates that the areas positioned as a tourist destination are being compromised by bad smells emanating from the sea, as well as poor air quality. This is expected to cost the region between $1.7 billion and $8.6 billion in long-term economic losses due to the degradation of the Salton Sea (*Tourism Economics* 2014). Areas that gain their economic strength through agriculture will also be affected as particulate matter has the potential to damage the growth of crops that will negatively impact the multibillion-dollar agriculture industry operating in the Coachella and Imperial valleys (Cohen, et al. 1999).

The seemingly simple solution to the problems facing the shrinking sea is to provide additional inflow so that the volume of the sea is maintained. The problem with this is twofold. First, the primary source of water for the Salton Sea—the Colorado River—is already allocated to the full extent of its historical flows to various stakeholders. Acquiring any water for the Salton Sea must necessarily require negotiation among these stakeholders to arrive upon an agreement that involves one or more of them relinquishing a portion of their water allocation to the Salton Sea. The second issue pertaining to reallocating water from the Colorado River is that the previously mentioned system of allocations was predicated on false assumptions that greatly overestimated the annual flow of the river, resulting in an over-allocation of water. This will be elaborated further in the next section, but this situation leaves us in the position of having to negotiate a sustainable allocation of water for the Salton Sea in a water landscape that is already in a state of bankruptcy.

The Salton Sea region includes major agricultural operations and urban centers. The first major agricultural stakeholders in the region are the farmers of the Imperial Valley, who are represented by the Imperial Irrigation District (IID). The agency was formed in 1911 after years of uncertainty regarding the supply of water because of poor management by private water companies (Hundley 2009). Currently, the IID presides over the majority of the area in which the Salton Sea resides. They service a population of over 150,000 and an agriculture industry that nets over $1 billion in annual profits. Currently they have an allocation of 2.6 million acre-feet of Colorado River water. It is important to note that this water exists as a present "perfected right," which means that on occasions when a shortfall exists the IID's water allocation must be satisfied before the other stakeholders' (Imperial Irrigation District 2018).

Our second major stakeholder, the Coachella Valley Water District (CVWD), was formed in 1918 and encompasses both major agricultural operations and urban centers. CVWD has afforded 450,000 acre-feet of water per year from the State Water Project, which supplies the agricultural industry as well as 373,100 permanent residents, and up to 3.5 million seasonal residents and tourists. The agriculture industry in the Coachella Valley produces a profit of over $500 million a year and predominantly utilizes drip-irrigation and other micro-irrigation methods. This stakeholder is also unique in the sense that it includes a tourism industry that is linked to the Salton Sea itself (Coachella Valley Water District 2001, 2005, 2010, 2015, 2017).

The Metropolitan Water District (MWD) is the only stakeholder involved in the affairs of the Salton Sea that can be considered exclusively urban. This does not mean that there are no agricultural operations in the service area, only that these operations are too small to be considered within our scope of research. It was founded in 1928 in response to a growing urban population, along with shrinking water resources in Southern California, and it was charged with managing and delivering water from the Colorado River to the urban southern coast (Hundley 2009). MWD currently services Los Angeles County, Orange County, as well as parts of Riverside, San Bernardino, San Diego, and Ventura counties. This service area provides for the water needs of over 19 million residents. The MWD is a major part of the California State Water Project and requisitions water from the Colorado River, as well as the Sacramento-San Joaquin River Delta. From the Colorado River, 1.35 million acre-feet are extracted annually (Metropolitan Water District 2018).

The last stakeholder involved in the Salton Sea is the San Diego County Water Authority (SDCWA), which is legally a part of the MWD but due to its history of acting as an autonomous stakeholder in Salton Sea negotiations, will be considered as an individual stakeholder for the purposes of this research. Prior to World War II, San Diego County was able to meet most of its water needs locally through a system of reservoirs and local streams. Following establishment of a major base of military operations, San Diego's population increased drastically resulting in a water shortage from existing reservoirs unable to meet the needs of the region. It was in 1944 that the San Diego Metropolitan area formed a unified water authority that could secure water for the city. This became the San Diego County Water Authority, which would not receive water from the Colorado River until 1947. Today the SDCWA supplies over 3 million residents within the County of San Diego. It has an annual entitlement of 330,000-acre feet per year, and 180,000 acre-feet of water is delivered each year from the Colorado River Aqueduct ,which is owned by the MWD (San Diego County Water Authority 2018).

Previous Relevant Work on Allocating Scarce Water Resources

While much published work on allocation of scarce water does exist, we focus in this section on either bankruptcy allocation or allocation of water in the Colorado River basin under scarce water conditions.

The work of Mianabadi, et al. (2015) discusses water allocation among separate governing entities by applying a bankruptcy model to the Tigris River. They had determined the allocation of water based upon the "weight" of a given stakeholder in the group, which includes Turkey, Syria, and Iraq. These weights were predicated, based on multiple factors, including proportion of population that is dependent on the watershed, and the power of a stakeholder. Though most importantly the weight of a stakeholder was based upon the amount of water that is contributed to the watershed by the hydrology of each stakeholder's jurisdiction. A larger weight would entail a greater allocation and heavier stakeholders would receive larger quantities of water.

In Iran, basin-wide water allocation frameworks were developed by Oftadeh, et al. (2016) for Lake Urmia, based on the quantity of water required by the stakeholders and referred to as the PRO method. This disregards the "on-paper" claims of stakeholders, only utilizing what is being used currently and historically. The PRO method is also weighted in favor of the agriculture sector as the priority. It thus does not address urban and agricultural sectors as equally competing interests.

Madani and Dinar (2013) indicate four major governance models for managing groundwater in situations of overuse of the scarce water supplies. The first of these is quota-based management, in which the regulator establishes a maximum amount of water that can be drawn by stakeholders. The second model is groundwater status management, in which the groundwater level is not allowed to fall below a preestablished level. Tax-based management imposes taxes on the use of groundwater, allowing the market to run its course. The last governance model is bankruptcy management, in which the groundwater table is treated as a bankrupt entity whose assets must be distributed among the users. This is generally fulfilled either through asking each stakeholder to reduce their use by a given proportion, referred to as proportional bankruptcy; or by a constrained equal award model, in which more vulnerable stakeholders are satisfied before more resilient stakeholders.

Reallocating water within the Colorado River basin has often taken the form of market-based solutions, in which stakeholders (state signatories to the Colorado River Compact in this case) are afforded the ability to trade water rights among themselves. Such proposals focus on replicating water markets at the interstate level by facilitating wider governing bodies to oversee the transactions. These methods can be projected to produce a more flexible allocation framework, in which stakeholders pay the true cost of water, leading to a more equitable and efficient distribution. Market-based solutions cannot account for situations that exhibit market failures, nor does it account for intrastate water allocation deficiencies, as these already allow for market-based water trading (Booker and Young 1994; Clyde 2008).

Within the rights framework of the state of California, the adoption of bankruptcy-based approaches to water scarcity has been shown to have the benefit of setting the tone for water negotiations. This refers to a situation of water scarcity within the Sacramento River Delta region, in which establishment of bankruptcy rules within that region gives stakeholders the impression that they will not receive the ideal amount of water from the outset. This allows the regulators to operate and establish retractions with less pressure from existing water rights frameworks and stakeholder expectations (Klein 2012). The “top-down” approach of bankruptcy governance also differs from existing frameworks of water reallocation in the Salton Sea region, in which water conservation has been fulfilled largely though cooperative agreements and market-based solutions, such as the Quantification Settlement Agreement (QSA) or the Lower Basin Drought Contingency Plan.

The above-reviewed works use several approaches for the allocation: (1) a formula allocation (bankruptcy allocation), a market mechanism allocation, and a legal arbitration allocation. But there is another approach: the social planner allocation which, in theory, provides the greatest degree of welfare for the region by efficiently allocating scarce common pool resources to its highest value. What is needed, then, is to agree among the users on the allocation of the welfare created by the use of the water, which may not be obvious. This was utilized within the Nile Basin by Nigatu and Dinar (2015), who established clear implications for the use of this method in allocating water. First is that the most efficient allocation under the social planner approach may not necessarily align with either existing uses or entitlements. This was the case with Egypt, which was found to be the most efficient user and thus would be afforded the most water in excess of the previously established unilateral use arrangement. It was also discussed that any allocation scheme that does not utilize the social planner approach will produce inferior regional welfare. This does not necessitate the end of other approaches, because total welfare is not the only consideration and the welfare produced by the social planner can be used to measure the efficiency of other methods.

The social planner methodology was also utilized in Spain by Kahil et al. (2016) to assess various scarce water allocation policies in the region surrounding the Albufera wetland in the Jucar River basin. A report from the United Nations concerning water allocation in Western Asia considers this welfare in terms of the marginal benefit of an additional unit of water. It states that the value of a unit of water applied to a given stakeholder should be greater than or equal to the value provided to the region if it is given to a different stakeholder (United Nations 2003). Research into the social planner approach as it applies to the Caspian Sea indicates that this approach may not necessarily produce a sustainable arrangement, due to the fact that individual stakeholders may not place cooperation as a higher priority than their own interests. Additionally, stakeholders may not accept the socially optimal solution if they deem it inequitable (Read 2014). Yet an analysis into international water allocation in the Middle East by Becker (1996) indicates that it is possible for stakeholders to agree to such policies if they are compensated within the framework of a water market. It is further noted that such markets do not generally arise on their own but require a third party to set up and oversee the market.

Analytical Framework

We start with explaining the deficit concept related to the social planner and the bankruptcy allocations we use.

Assume that a regional regulator (such as the 1922 Colorado compact) allocates a given amount of water Q among n users such that $\sum_{i=1}^{n} q_i \leq Q$, where q_i is the agreed (in the compact) quantity to be provided to user i. However, given the natural climate in the region (see Figure 1) the regulator cannot meet the overall quantity Q and faces a significant lower available amount, Q^*. The deficit, Q-Q^*, is now to be allocated among the different n users such that each gets $q_i^* \leq q_i$. Users include irrigation districts, utilities that provide water to household consumers, and the

Salton Sea, which is a recreational attraction in the region. In the following examples, we provide the formal presentation of the allocation approaches we use in this paper.

Social Planner Allocation

A social planner considers reducing the water allocations to each user such that at the end of the process the regional welfare will be maximized. The social planner allocates the available water $\sum_{i=1}^{n} q_i^* \leq Q^*$ such that the marginal welfare is equalized.

The optimization problem of the social planner is (in a static setting):

$$Max\ W = \sum_{i=1}^{n/S} D_i^j\ |q_i^* + S\ |q_S^*$$

where W is the regional welfare, D_i^j is the area under the inverse demand function of user i, i=1, ..., n/S, and S is the welfare function of recreation that is associated with the quantity of water in the Salton Sea.

Subject to:

(1) $\sum_{i=1}^{n} q_i^* \leq Q^*$

(2) $Q^* \leq Q$

We refer to the social planner as the first allocation model.

Bankruptcy Allocations

We use two bankruptcy allocation measures: the proportional rule and the constrained equal award rule. We will refer later to these as our second allocation model and third allocation model.

The bankruptcy proportional allocation rule allocates a reduction of Q-Q* among the n users such that each user is faced with a reduction that is proportional to their water compact allocation.

The percent reduction faced by user i under this rule is $R_i^P = \frac{Q-Q^*}{Q} q_i$. It has been argued that the bankruptcy proportional allocation rule may benefit users with relatively larger original allocations, and thus it is not valued as fair, although it is efficient (Madani and Dinar 2013).

The constrained equal award allocation rule allows the regulator to introduce social preferences, such as weights on the bankruptcy allocations to certain users. One example could be a higher (since we deal with reductions, this means actually a lower) weight to the Salton Sea in recognition of its regional welfare effects, or a preferred weight to the urban centers due to their sensitivity to water availability. The percent reduction faced by user i under the CEA rule is $R_i^{CEA} = \frac{Q-Q^*}{Q}\phi_i \cdot q_i$, where ϕ_i is the weight assigned by the regulator to user i, with $\sum_{i=1}^{n}\phi_i = 1$. In our analysis, we applied the rule constraint that no user can be allocated an amount of water that is higher than any of their historical allocations.

Welfare Loss Calculations

The calculations of the welfare losses of each user, and of the entire region, are based on the increase in willingness to pay for water after reducing the allocation that was awarded to users by the 1922 compact. A demonstration of such calculation for a given user with a defined demand function is shown in Figure 2 (left panel). The calculation for a user with a water value function increasing from left to right is shown in Figure 2 (right panel).

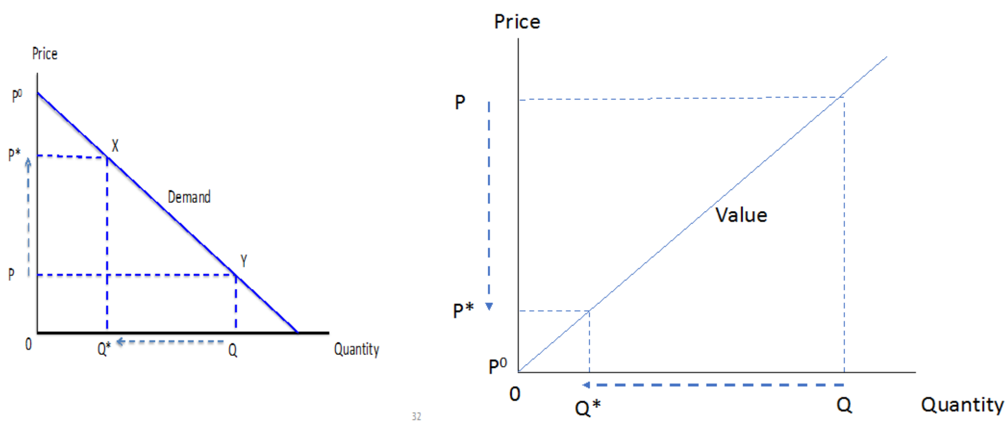


Figure 2: The welfare loss from reduction of the quantity allotted to user *i*.

The welfare under an allocation of Q is the consumer surplus below the demand curve and above the price line P (the triangle P^0YP). The welfare under the deficit case is the consumer surplus below the demand curve and above the price line P* (the triangle P^0XP^*). The loss in welfare is the difference between the triangles P^0YP and P^0XP^* which is the trapezoid P*XYP.

We developed an algorithm to calculate regional loss in welfare from the various water deficit allocations. Below is a general model that presents the principles that drive the calculations.

$$LW = \sum_{i=1}^{6}\left[\left(\int_{Q_i^1}^{Q_i^0} D_i(Q)dQ - P_{Q_i^1}Q_i^1\right) - \left(\int_{Q_i^2}^{Q_i^0} D_i(Q)dQ - P_{Q_i^2}Q_i^2\right)\right] + \left[\left(\int_{Q_7^1}^{Q_7^0} P_{Q_7^1}Q_7^1 - V_7(Q)dQ\right) - \left(\int_{Q_7^2}^{Q_7^0} P_{Q_7^2}Q_7^2 - V_7(Q)dQ\right)\right]$$

where LW is the regional loss of welfare, $D_i(Q)$ is the demand function of user i, Q_i^1 is the quantity allotted to user i under the original allotment scenario, Q_i^2 is the quantity allotted to user i under the deficit allotment scenario; $P_{Q_i^1}$ is the price faced by user i when allotted quantity Q_i^1. The index 7 refers to the Salton Sea region. For simplicity of presentation, we use results that pertain to the consumer welfare calculated at the level of the allocation of water under deficit and not to the loss in consumer welfare between the compact allocation and the deficit allocation (Appendix 3).

Empirical Methodology

Our methodology for optimal allocation of water from the Colorado River will be performed in two stages. The first stage is an estimation of a relationship that quantifies the value of water for each stakeholder at each allocation level. The second is the application of allocation methods using the estimated water value relationships. The allocation methods include a social planner approach, the proportional bankruptcy based allocation, and the constrained equal award allocation.

The value of water will be represented by demand curves of consuming sectors, indicating the willingness to pay for an additional unit of water in the case of three urban stakeholders, and the derived demand for an additional unit of water for three agricultural stakeholders, using the residual approach (Young 2005). Each of the six stakeholders in the region uses Colorado River water for urban/residential consumption and for agricultural production. A seventh user is the Salton Sea, which is identified in our paper as being engaged with recreational uses of the water. Each of these seven sectors will require different sets of input data for estimation of the water demand and water value functions.

Urban water value is determined by the extent users are willing to pay for water. Agricultural water value is determined by the additional dollar amount provided from the application of an additional unit of water. The regional benefits are determined by utilizing data on water inflow to the Salton Sea, recreational visits to the Salto Sea region, and monetary spending in the region. Each of these methodologies will be explored in more detail in the next section. Once we have established the relationship between quantity and value of water for each of the seven stakeholders, we then determine the effects of allocations to ensure social welfare, social justice, and robustness (Madani and Dinar 2013).

We employ the residual approach (Young 2005) for each of the three agricultural users in the region. The residual approach subtracts the costs of producing a crop and net cost of applying water from the revenues gained in the sale of that crop, leaving only the amount of revenue that is attributed solely to the applied water. We determine the costs and revenues associated with growing crops by pulling data from the University of California Cooperative Extension crop budget in the three counties of the Salton Sea region (Imperial, Riverside, San Diego). By ordering the crops in a declining value per unit of water and by accounting for the area grown of each crop, hence, the total amount of water used to irrigate each crop, we can obtain the derived demand for water by each of the agricultural water users.

The value of water for urban uses can be derived from a demand curve for urban water, interpreted as the willingness of end users to pay for an additional unit of water. Changes in available amount of water affect the consumer surplus (Moncur 1987; Bithas and Stoforos 2006). We utilize these curves to foresee the potential results of a loss in allocation for an urban stakeholder and the feasibility of implementing a given reallocation scheme. This method has been implemented and successfully replicated statewide across California (Dziegielewski and Optiz 1991). We applied the findings in Dziegielewski and Optiz (1991) to the three urban centers in the Salton Sea Region.

To determine the value of water to the Slaton Sea itself and compare it to agricultural or urban uses, we estimate the value of the recreational sector of the Salton Sea. We employ the approach used by Iamtrakul et al. (2005) and by Esteban and Dinar (2015), who estimated the relationship between inflow of water into the Salton Sea and the number of tourist visits and dollars spent by tourists in the region. This is a viable comparison due to the relationship of the tourism industry that is being directly tied to the Salton Sea visits, which can be affected by the sea's health or by other tourist activities that can be negatively impacted by the Salton Sea's effects on air quality and ecosystem health (Schwabe et al. 2008). The strength of this form of valuation is in the fact that it allows the value given to a natural feature to be quantified and directly compared to the value placed on water within the urban and agricultural sectors.

Once the demand functions for the urban and agricultural sectors and the value function for recreational water in the Salton Sea region are estimated, we evaluate the impact of various allocation methods on the sectoral and regional welfare. We apply two allocation methods: the social planner approach, and the proportional deficit allocation. The social planner model is based upon maximizing the regional welfare by allocating water to the stakeholder that provides the highest marginal welfare for an additional quantity of water. The proportional deficit allocation has three subsections: The first is based upon the proportion of available water each stakeholder has used during historic drought years. The second provides stakeholders with an allocation from the available water after the deficit is applied, which is proportional to their current legal claims. The final form of proportional allocation model considers that the senior rights of the IID are upheld in any deficit scenario (Sechi and Riccardo 2014).

Empirical Application

In this section we begin by estimating the derived demand for agricultural water use, utilizing existing crop values, costs of production, and water used. We then implement the demand curves developed for urban water use by Dziegielewski and Optiz (1991). finally, we derive the value of water afforded to the Salton Sea by running a regression on the inflow of water into the sea, and tourist visits and their spending. Once our value of water is derived, we describe in greater detail how our allocation models are applied.

Estimating Irrigation-Agriculture Demand

Not all stakeholders will require valuations in all sectors. The Metropolitan Water District of Southern California (MWD) will require only an urban use valuation. The Imperial Irrigation District (IID) will consider only an agricultural use valuation, whereas both agricultural and urban use will be valued for the Coachella Valley Water District (CVWD). The San Diego County Water Authority (SDCWA) environmental water valuation will be applied only to the Salton Sea itself.

Three stakeholders with major agricultural operations whose water consumption will be addressed are the IID, the CVWD, and the SDCWA. While agriculture produces value of over $1 billion for the IID and the SDCWA, as well as $500,000,000 in the CVWD, the purpose of this valuation is to determine the value that a single acre foot of water contributes to the economy so we can determine the potential economic loss in a given deficit allocation framework.

We apply the residual method to determine the value of water as it pertains to agricultural uses. This involves subtracting the cost of producing an acre of crop, minus the cost of water from the value that this acre of crop produces. This leaves only the value that is attributed to the application of water. We are then able to divide the value of applying water to an acre of crops by the number acre feet of water applied to an acre. This allows us to determine the value provided by applying an additional acre foot of water for each crop. Costs do not include overhead, which would be paid by the growers regardless of whether or not they decided to grow a particular crop (Young 2005).

The value and cost of growing crops, as well as cost and quantity of water applied, has been determined through existing crop cost/return studies (UCCE Riverside 2018; UCCE Imperial 2018; UCCE San Diego 2018). The most recent cost/return studies have been published for the year 2017, thus all crops are assessed at their 2017 value. In the case of crops with no published cost/return studies for 2017, we utilized studies from earlier years and adjusted for inflation.

Not included in the agricultural valuation for the IID are what is listed as "miscellaneous crops and cattle" in official crop reports, as well as aquatic products. This is because we are unable to determine the composition or value of these individual products, thus rendering them unable to be factored into our valuation. It is important to note that aquatic products and miscellaneous livestock produced a gross value of $60,889,000 (Imperial County 2018). The agricultural valuation for the CVWD is similarly limited to the available data on the cost of growing an acre of crops.

The valuation of the SDCWA is limited by a small body of official cost/return data on nursery plants, in addition to official crop reports aggregating all nursery plants into broad classes (i.e., succulents, perennials, fruit trees). This aggregation makes it difficult to determine the production cost of individual crops. We are able to obtain an estimated production cost and water needs. This was done by utilizing representative plants within that category whose production costs act as a stand-in for all crops in the category. In the example of perennial flowers, only cost and return studies for carnations have been made available through the UC Cooperative Extension, thus the cost of producing carnations is applied to all perennial production within the county. The agricultural demand functions for water can be found in Figures 1, 2, 3, for IID, CVWD, and SDCWA, respectively. For our estimated derived demand equations see Appendix 3.

Estimating Irrigation-Agriculture Demand

We applied the residual approach (Young 2005) to the data from three irrigation districts in the region in order to obtain the economic values per A-F for each of the crops grown in that district's derived demand. The derived demand curves are shown in Figures 3, 4, and 5 for Imperial Irrigation District, Coachella Valley agricultural water, and San Diego County Authority agricultural water, respectively. We use the quantity-economic value pairs to estimate for each irrigation district the derived demand function (Table 1).

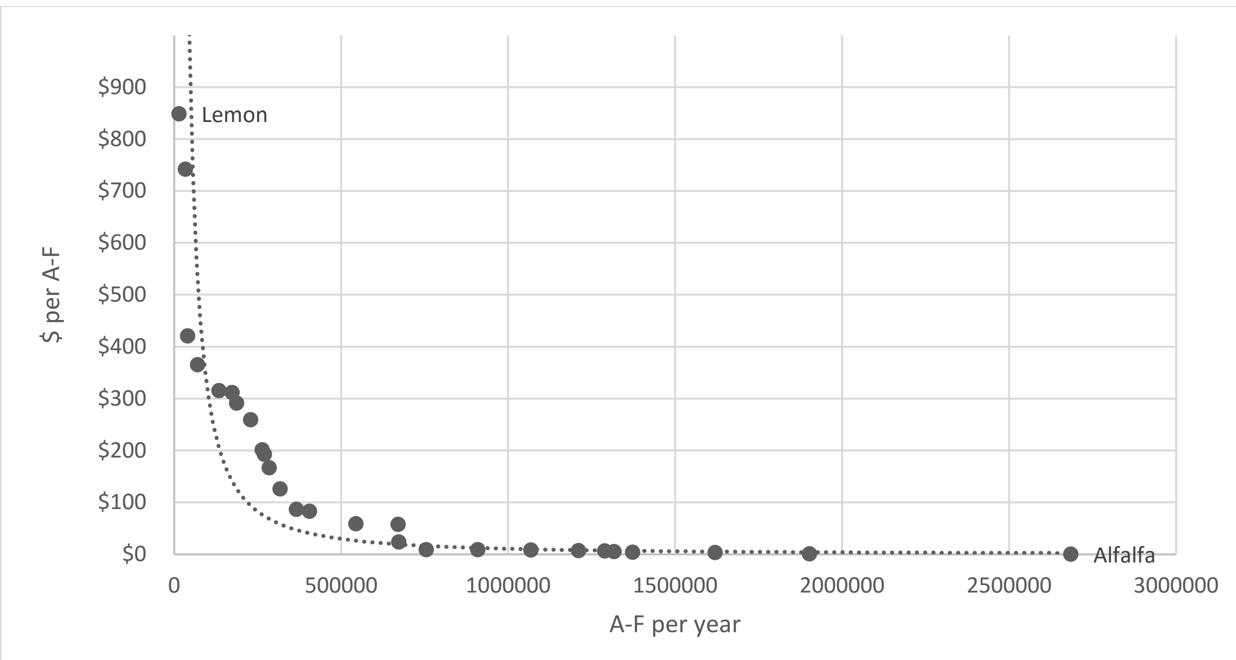


Figure 3: Imperial Irrigation District agricultural-derived water demand curve

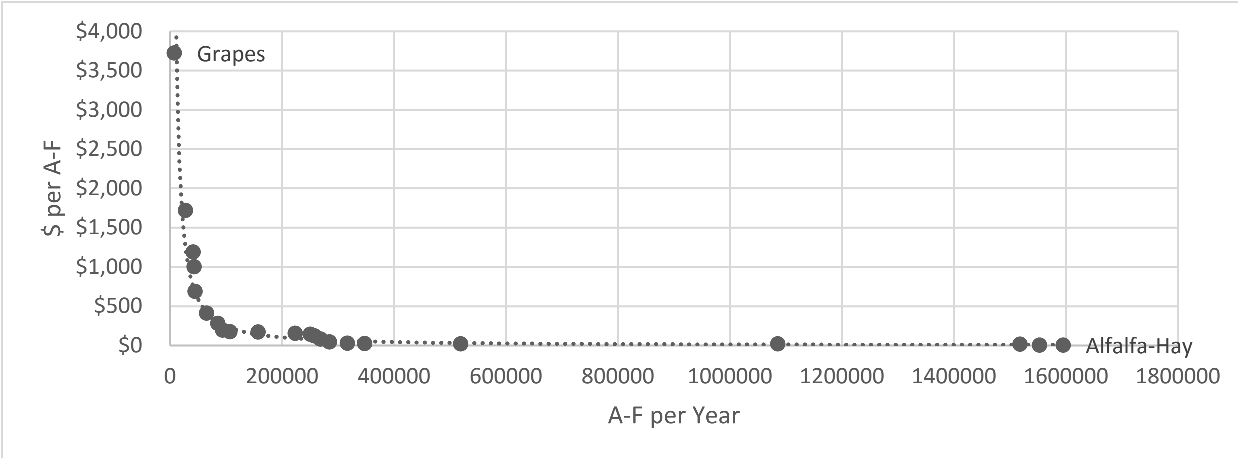


Figure 4: Coachella Valley Water District agricultural water-demand curve

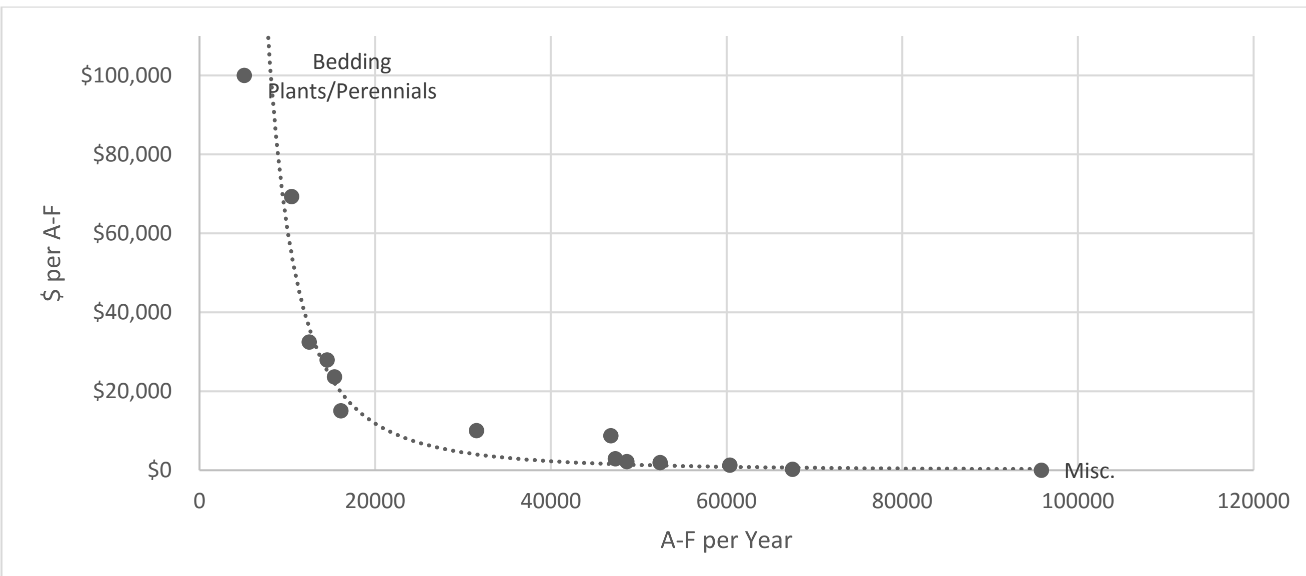


Figure 5: San Diego County Water Authority agricultural water-demand curve

Estimating Urban Demands

We selected demand functions as the means of estimating urban water value for the MWD, the SDCWA, and the CVWD urban water districts.

In order for the demand function method to act as an accurate representation of the value of water for urban stakeholders, we must make three assumptions. First, that the statewide price elasticity is both applicable to the urban regions of Southern California and is constant along the demand curve. Second, that we can consolidate monthly fluctuations in water usage into a single demand function for the year. Third, we have a collection of assumptions that underlie all demand functions, although most pertinent to our research is the assumption that usage needs and consumer preferences will remain the same in the future and when scarcity is applied.

We applied the demand function methodology to determine the value of water within the state of California, which was developed by Jenkins et al. (2003). It relies on factoring in the regional price elasticity (expressed as *ε*), as well as an integration constant (expressed as *C*), along with the price *P* and quantity of water, *Q*, to develop the demand curve. Important to this method is utilizing the correct price elasticity, which was that used for the MWD estimated by Dziegielewski and Optiz (1991). Their methodology took into account the seasonal fluctuations of water demand from winter (-.240) to summer (-.390), which we have aggregated to produce a single annual price elasticity of (-.315). It is important to note that we will be utilizing the price elasticity developed for the MWD for all urban stakeholders in the Salton Sea region. This is due to similar characteristics between all MWD-served districts, and a lack of existing price elasticity data for CVWD and SDCWA. The latter is being included as a part of the MWD in Dziegielewski and Optiz's (1991) study.

We first derive the integration constant represented by $C = \ln(P) - \{\ln(Q)/\varepsilon\}$, where P is the observed price of water for the given stakeholder, and Q is the observed quantity of water drawn by that stakeholder in the year 2018. ε represents the regional price elasticity. This will then be factored into our demand function represented by $P = e^{\frac{\ln(Q)}{\varepsilon}+C}$.

The graphs of the urban demand functions for MWD, SDCWA, and CVWD, respectively, can be found in Figures 6, 7, 8. The pairs of water quantity-economic values are used to estimate demand functions for the various urban centers. Refer to Table 1 for the coefficients of the estimated demand functions.

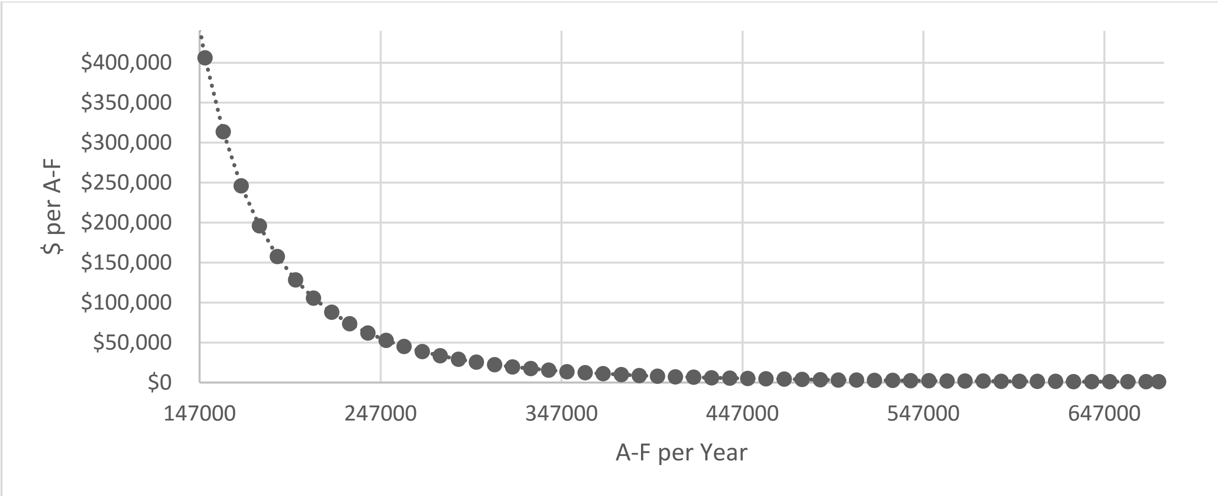


Figure 6: Metropolitan Water District urban water demand curve

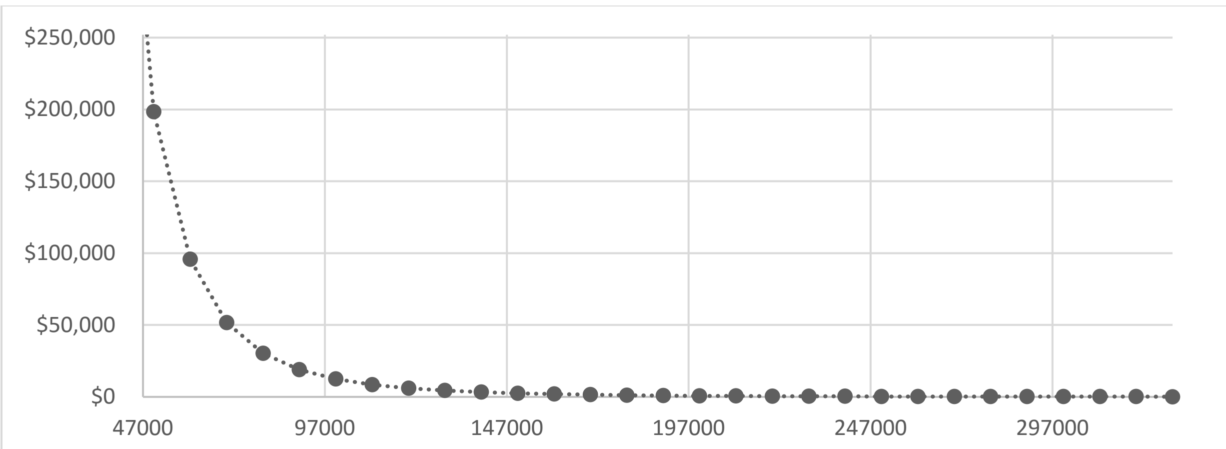


Figure 7: San Diego County Water Authority urban water demand curve

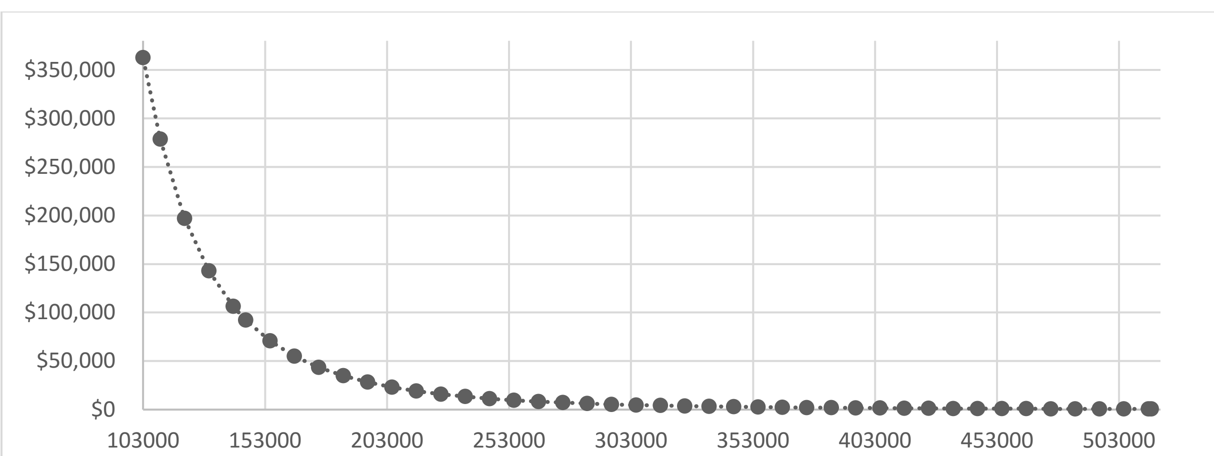


Figure 8: Coachella Valley Water District urban water demand curve.

Estimating Recreational Value

The travel cost method has the benefit of being more directly comparable to the valuation methods utilized for urban and agricultural users. It translates the recreational value of the Salton Sea into a dollar amount that can then be considered in terms of value of water per acre feet delivered to the Salton Sea. We are therefore able to compare the value per-acre feet delivered to agricultural, urban, and environmental/recreational uses.

We estimated a relationship between the total water inflow to the Salton Sea and the number of visitors to the region. The data concerning annual tourism visits and revenues has been extracted from the Greater Palm Springs Convention & Visitors Bureau (*Tourism Economics* 2014). Annual inflows into the Salton Sea have been established using data from the United States Geological Survey (USGS 2017). Using data for 2013-2018, we were able to estimate a linear relationship using OLS regression. We first plotted the linear relationship between annual water inflow to the Salton Sea and the number of visit in the region (Figure 9). Visitors to the region spent on lodging, dining, and attractions during their visits. These $ amounts, that vary with the amount of water flowing into the sea represent the value they attribute to the Salton Sea. (See Appendix 3).

We estimated a relationship between the inflow of water to the Salton Sea and the number of individual visits to the Salton Sea region. This relationship seems to be linear in the water inflow.

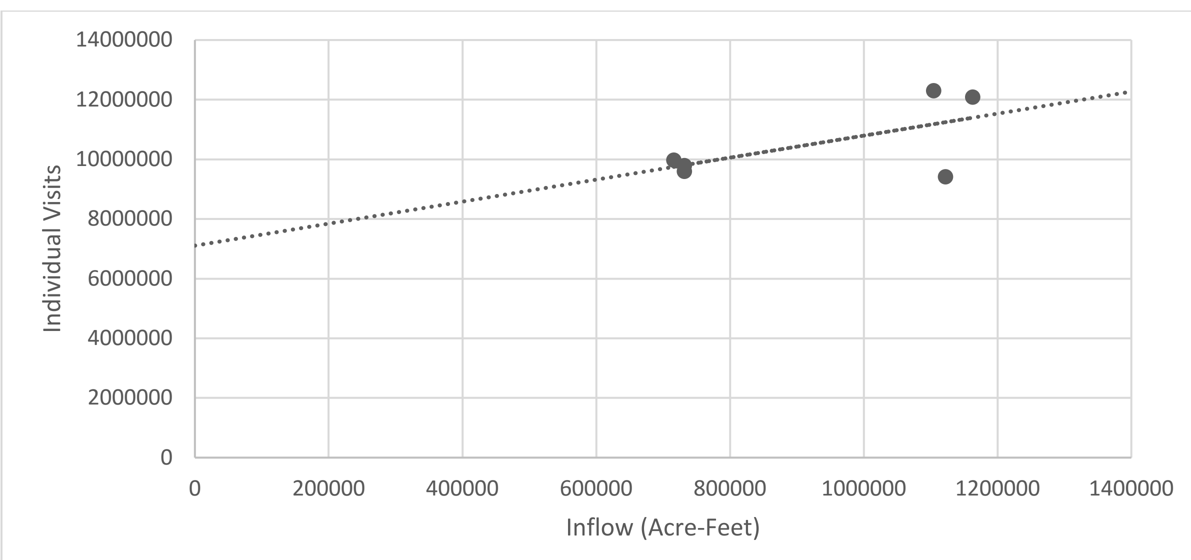


Figure 9: Individual visits to the Salton Sea Region as a function of water inflow to the Salton Sea.

A similar regression was used for the data of the dollars spent in the Greater Palm Springs/Salton Sea region and the acre-feet of inflow to the Salton Sea. We operate under the assumption that visitors to the Greater Palm Springs/Salton Sea region are motivated by the health of the Salton Sea ecosystem to visit the region (similar to Esteban and Dinar 2015). The environmental quality of the area is assumed to have a direct impact on those who would visit the sea itself, and an indirect impact on tourism in the region due to the hazardous air quality that the environmental degradation of the sea is responsible for. This means that the sea is assumed to be a major influence on visitation to the region regardless of whether those visits are to the sea itself or some other attraction. We used the same time frame (2013-2018) to plot the linear relations below (Figure 10). See Table 1 for the equations' coefficients.

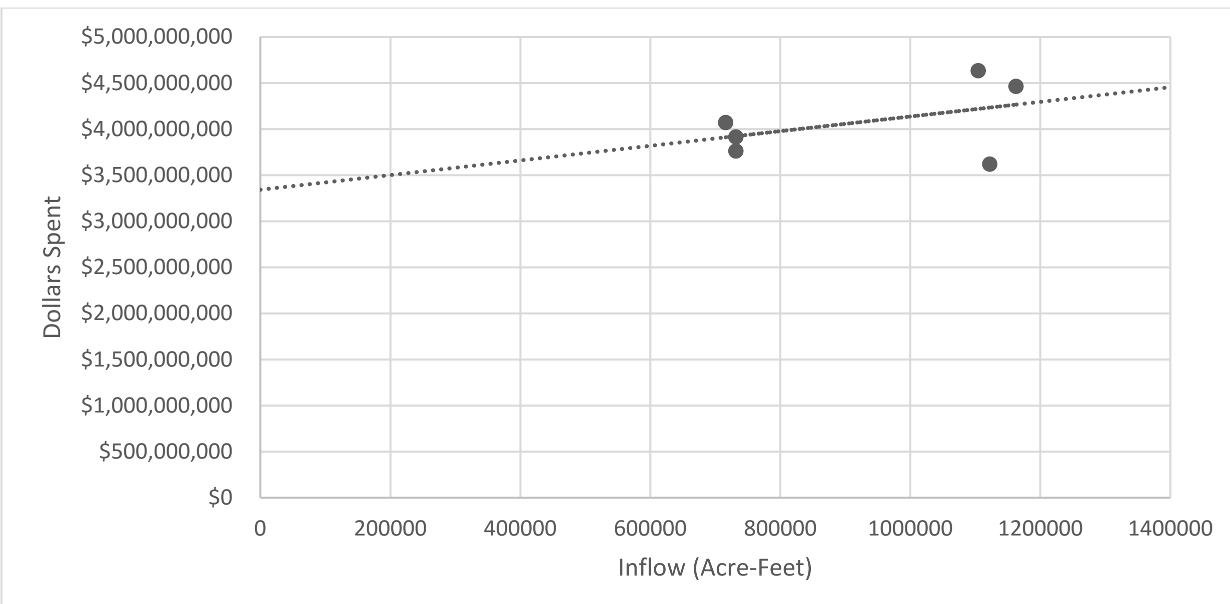


Figure 10: Dollars spent in the Salton Sea region as a function of water inflow.

Table 1 presents the estimated coefficients for all six demand functions in the agricultural and urban sectors, and for the economic value of water derived from tourism, in the Salton Sea region.

Table 1: Estimated equations of water demand in urban and agricultural sectors and of recreational water value in The Salton Sea Region.

Sector Variables	IID	MWD[a]	CVWD AG	CVWD URB[a]	SDCWA AG	SDCWA URB[a]	$'s Spent in the Salton Sea region	Salton Sea Tourism
Intercept	17.05 (24.59)*	60.58	19.94 (23.18)*	55.5	32.84 (9.43)*	55.48	3,171,912,314 (3.30)*	7,926,128 (3.09)*
W	-0.774 (-6.43)*	-4	-1.25 (-17.73)*	-4	-2.36 (-6.98)*	-4	1,039 (1.03)*	2.6 (0.91)*
F-Test	41.35 (9.84E-07)*		314.45 (1.06E-13)*		48.82 (1.46E-05)		1.05 (0.36)	0.83 (0.43)
Adjusted R^2	0.608		0.937		0.786		0.011	0.241
Number of Observations	27	55	22	22	14	34	6	6
Equation Type	Log-Log	Log-Log	Log-Log	Log-Log	Log-Log	Log-Log	Linear	Linear

Note: t-test in parentheses. *=Significant in 1% or less.

[a] Coefficient calculated based on Dziegielewski and Optiz (1991).

[b] Given comment a, statistical performance is not reported due to extraction from existing reported equations.

Policies for Allocation of the Deficit in Water Supply Among the Various Water-Rights Holders

The policy of allocating a deficit is best viewed from the lens of a social planner approach. By this we mean that the planner's goal is to ensure the highest general social welfare in the region, which entails minimizing losses incurred through water restrictions. Considering that we will determine the value of water using monetary figures, the regional welfare will be determined through the dollar value provided to the region by the application of water to different economic activities.

Bankruptcy Allocation

A bankruptcy allocation treats scarce common pool resources as a bankrupt entity, which must have its deficit assets distributed among stakeholders to whom more was promised than can be allocated. They also indicate that the best regulatory framework is one that ensures social welfare, social justice, and robustness (Madani and Dinar 2013).

In pursuing an allocation based upon a social planner, we evaluate the social welfare (measured as the consumer surplus) produced within each sector within the jurisdictions of the major stakeholders. This is so that we may distinguish between commercial and public interests as we calculate the most beneficial allocations. The simulations for these water allocations have been derived by developing a model that utilized our existing sector-stakeholder demand curves to indicate the potential benefits of providing a proportion of the long-term sustainable withdrawal for the region. These proportions ranged from no allocation at all to the maximum possible volume of water that a given stakeholder-sector could potentially utilize. We used this model to assess the highest proportion each stakeholder-sector could receive until an additional allocation of water would produce a greater amount of social welfare when placed elsewhere. Thus, the maximum amount of welfare a single stakeholder-sector could produce relative to the other stakeholder-sectors is derived.

Our second model, following the relative proportional rule of bankruptcy allocation, does not break our stakeholders into sectors, because this model is dependent on both the agreed entitlement of water and the total use of water for each stakeholder. The first simulation for this model involves taking the proportion of the total water supply that each stakeholder uses in a given year and scaling it down to the previously mentioned amount, which is sustainable for the state of California to utilize. The second simulation is derived from a similar method, which is instead applied to the allocations that each stakeholder has been promised by the regulator or in a water-transfer agreement. The last simulation is similar to the first, in that it is derived from the proportion of existing use but with the addition of an allocation set aside for the Salton Sea, and it is designed to close the gap between current inflow rates and a historically sustainable flow.

Our third allocation model is a version of the constrained equal award rule of bankruptcy allocation. A constrained equal award allocation model is one in which the available pool of resources is distributed equally among all stakeholders, usually with some form of constraint or weighted preference set by the regulator (and expressing social preferences). In this case, we will be dividing the available pool of water equally among all stakeholders, with the constraint that no stakeholder receives more than their maximum historic entitlement. This should result in a model in which stakeholders who have historically used less water are favored.

We will also address the matter of the present perfected rights held by the IID, which mandates that in the event of a scarcity situation the needs of the IID must be satisfied prior to any other stakeholder. The IID has agreed to water restrictions within the district in past agreements, such as the QSA. However, when developing a new model of reallocation, we cannot rely on the assumption that the IID would agree to such terms and limit its water intake. Therefore, we have developed two separate scenarios for our models: the first is a scenario in which the IID agrees to limit its water usage according the same rules as all other stakeholders. The second scenario is one in which the IID's resent perfected rights are upheld and will not reduce their water allocation while the burden of deficit is placed on all other stakeholders.

Water Delivery Simulations

To derive the extent of the water bankruptcy, we have utilized data of historic Colorado River flows along with historic allocation amounts (Table 3). Most importantly, the 1922 Colorado River Compact assumes that the Colorado River will have a flow equal to or greater than 16,450,000 acre-feet per year and divides this among the major stakeholders. The state of California is entitled to 4,400,000 acre-feet per year. For each year's annual flow, we have subtracted the amount of water that would be used if all beneficiaries of the Colorado River Compact take their full allotment (16.45 MAF). These overdrafts are larger than California alone could account for. In order to determine what proportion of the shortfall is to be taken from California, we have derived from each year's shortfall a proportion that is equivalent to California's original allotment (4.4MAF/16.45MAF=0.267).

From this we can assume that for a given year, Californian stakeholders are to be responsible for 26.7% of the shortfall. Take the year 2010 as an example, in which the overdraft on the Colorado River was -5,820,846AF. It would be impossible for our stakeholders to manage such a large overdraft of the entire river basin. Yet, if we assume that California is only responsible for a portion of the overdraft that is equivalent to its allotment, then our stakeholders would be responsible for managing 26.7% of the overdraft: (-5,820,846AF*.267=-1,554,166AF).

Our stakeholders within the Salton Sea region would collectively need to reduce their usage by 1,554,166AF in order to ameliorate the 2010 overdraft in the Colorado River basin.
From Table 2, we see that the smallest deficit that can be attributed to California users in the last decade was -350,285 in 2013, while the largest recorded deficit was -2,068,985AF in 2011. From this we establish our three scenarios of varying degrees of deficit. The lowest level of deficit we will prepare for in our projections will be 400,000AF. Our medium severity deficit will be 1,000,000AF. Finally, our high-severity deficit level will be 2,000,000AF, as this roughly corresponds with the highest recorded deficit -2,068,985 acre-feet (Table 2).

Table 2: Historic Colorado River flows and stakeholder use/overdraft. All values are in acre-feet (except where otherwise indicated).

Year	Colorado River Flow	Total Treaty Allocation	Total Balance/ Overdraft*	California withdrawal	Treaty Allocation to California	CA Overdraft**	IID	CVWD	MWD	SDCWA	IID (%)	CVWD (%)	MWD (%)	SDCWA (%)
2017	17,395,012	16,450,000	945,012	4,026,515	4,400,000	252,318	2,548,171	335,321	436,181	240,846	63.28	8.33	10.83	5.98
2016	14,319,476	16,450,000	-2,130,524	4,381,101	4,400,000	-568,850	2,504,258	356,358	763,622	233,401	57.16	8.13	17.43	5.33
2015	13,916,004	16,450,000	-2,533,996	4,620,756	4,400,000	-676,577	2,480,933	342,068	949,013	229,915	53.69	7.40	20.54	4.98
2014	15,138,072	16,450,000	-1,311,928	4,649,734	4,400,000	-350,285	2,533,414	349,372	893,580	282,754	54.49	7.51	19.22	6.08
2013	10,629,154	16,450,000	-5,820,846	4,475,789	4,400,000	-1,554,166	2,554,854	331,137	731,095	281,620	57.08	7.40	16.33	6.29
2012	8,700,992	16,450,000	-7,749,008	4,416,718	4,400,000	-2,068,985	2,903,216	329,576	458,870	277,249	65.73	7.46	10.39	6.28
2011	21,354,481	16,450,000	4,904,481	4,312,661	4,400,000	1,309,496	2,915,784	309,348	433,544	265,446	67.61	7.17	10.05	6.16
2010	13,952,496	16,450,000	-2,497,504	4,356,839	4,400,000	-666,834	2,545,593	306,141	838,267	260,794	58.43	7.03	19.24	5.99
2009	14,948,728	16,450,000	-1,501,272	4,358,074	4,400,000	-400,840	2,566,713	308,560	465,823	292,377	58.90	7.08	10.69	6.71
2008	17,255,224	16,450,000	805,224	4,498,810	4,400,000	214,995	2,811,800	325,000	1,008,721	328,615	62.50	7.22	22.42	7.30

*Calculated as year(flow)-16,450,000 (total treaty allotment commitment). Negative values indicate a deficit.

**Calculated as “total overdraft·0.267 (proportion of original entitlement afforded to California). Negative values indicate a deficit.

We determined that the range of possible deficits was between 0 and 2.5 MAF. This was divided into five sections of 0.5 MAF deficits. We counted how often each deficit range was represented in the 27 preceding years. This produced a normal distribution of the water deficit from the Colorado River (Table 2).

Table 2: Distribution of water deficit in the Colorado basin between 1988-2015.

Deficit range (MAF)	Number of years with such deficit
0-0.5	4
0.5-1	8
1-1.5	8
1.5-2	4
2-2.5	3

From this table we can observe that four out of the 27 years exhibit a small water deficit, 20 out of 27 years exhibit a medium level of deficit, and three out of the 27 years exhibit a high water deficit. Based on this distribution, we have determined the three ranges for the welfare analysis as: small deficit 0-0.5MAF with mean of 0.250MAF; medium deficit 0.5-2MAF with mean of 1.25MAF; and high deficit 2-2.5MAF with a mean of 2.25MAF.

With the set of the estimated demand functions and the range of water available for allocation, we were able in the section below to estimate sectoral and regional welfare (measured in consumer surplus) from allocation of the available water.

Bankruptcy Allocation Simulations

Social Planner Solutions

What follows is the comparison of welfare produced by the six proposed allocation methods that were discussed above. Included is the social welfare produced from individual stakeholders under each regime, as well as the total welfare produced once stakeholder welfare is aggregated. (Figures 11-13).

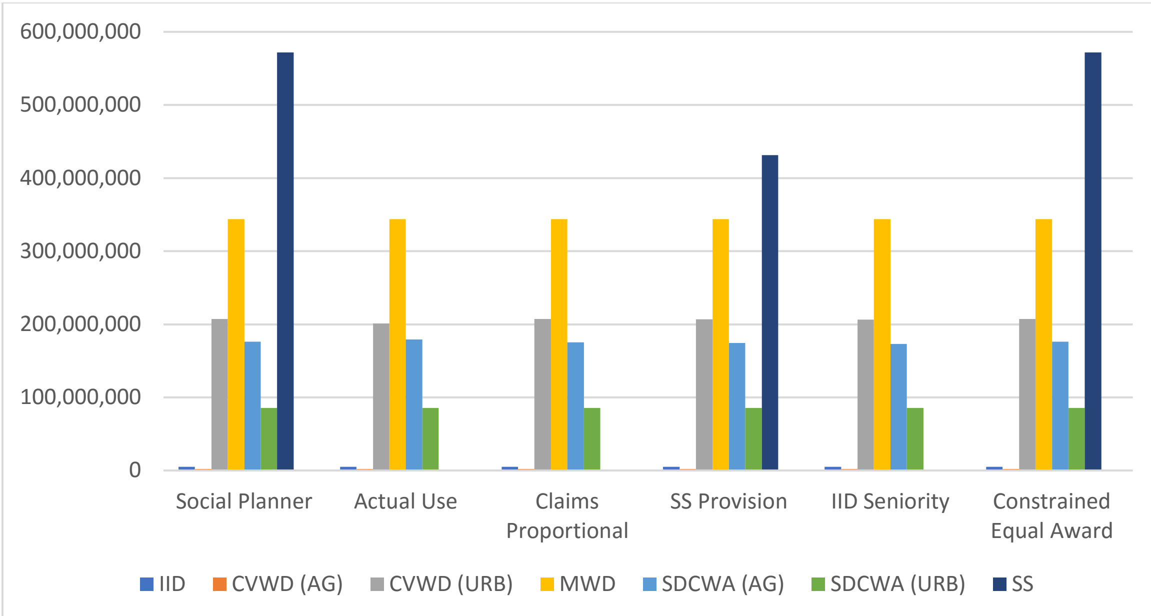


Figure 11: Welfare produced by six models under annual deficit of 250,000 acre-feet.

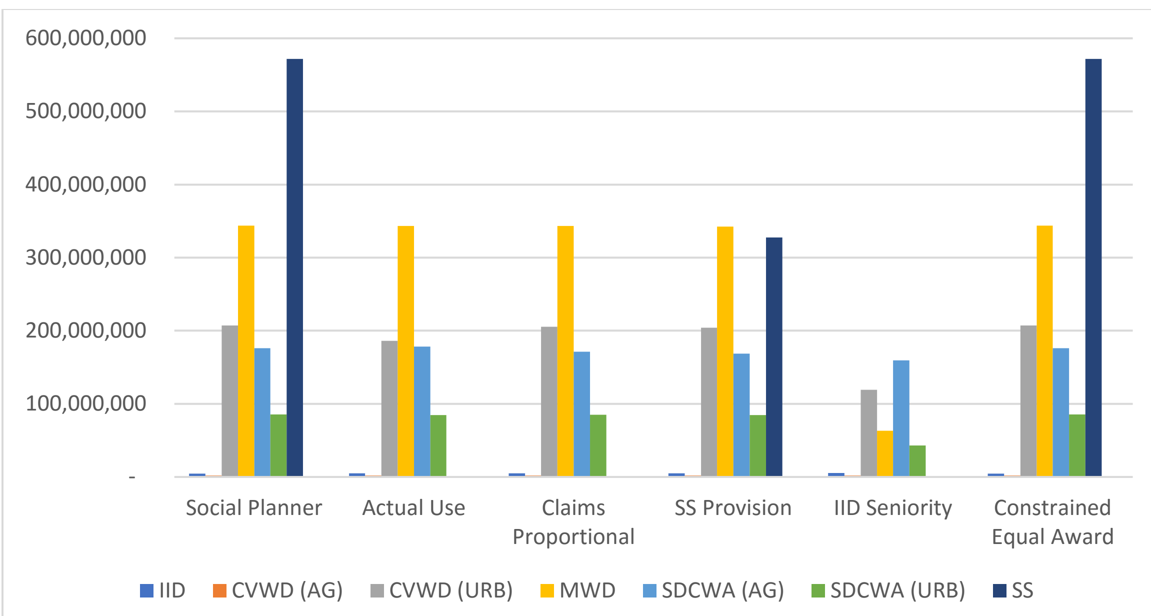


Figure 12: Welfare produced by six models under 1,250,000 acre-feet of deficit.

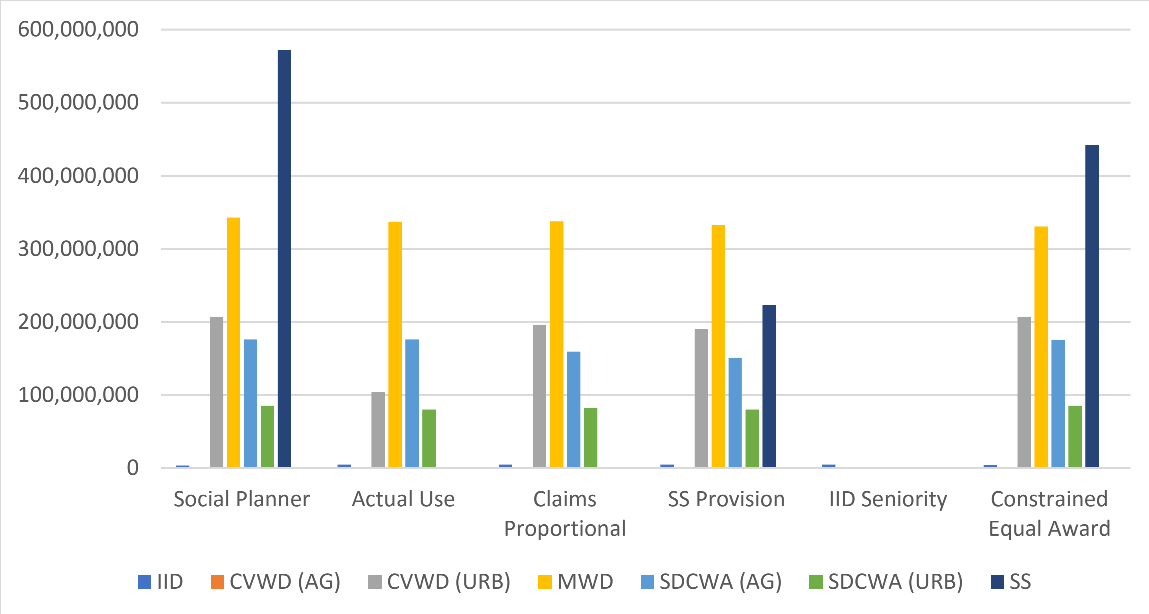


Figure 13: Welfare produced by six models under 2,250,000 acre-feet of deficit.

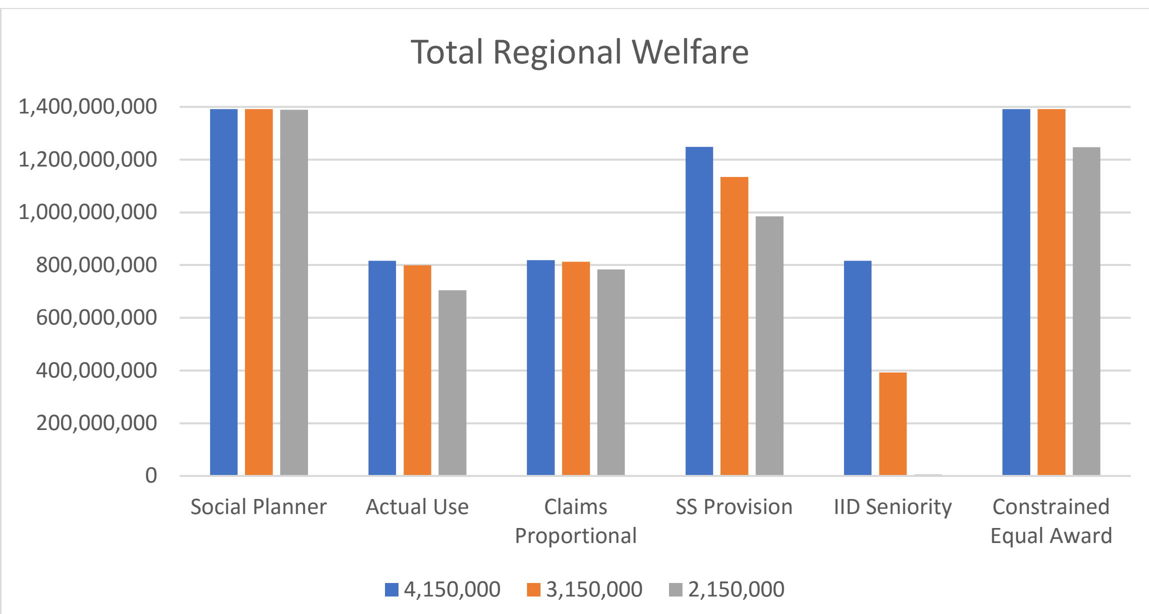


Figure 14: Total regional welfare produced by all models under three levels of deficit.

Results in Figure 14 suggest that welfare produced with small and medium deficits of the Colorado River water yields insignificant welfare losses in almost all simulated deficit allocations. The reason for that unexpected result is the relatively low value of water productivity in the high-amounts of water used. Therefore, reducing the available water for use in the range of low and medium deficits will result in small losses.

Discussion of Aggregated Impact Results

The social planner model does not weigh the water needs of agricultural stakeholders as highly as that of urban stakeholders. All simulations produced under this framework result in major losses to the agricultural industry, particularly the IID, which is left with only 275 thousand acre-feet of water in the lowest level of deficit. This is a major loss to the agricultural sector, as they have historically utilized an average of 2.5 million acre-feet a year (Table 2). A social planner model would ensure the welfare for the majority of the population, but in order to meet the provisions of this allocation numerous farms would need to shut down and thousands of acres would be left fallow. The agricultural sector of the SDCWA fares the best of all agricultural sectors, possibly due to the high value produced on a relatively small acreage, which allows it to produce greater regional welfare with less water. The urban sectors are valued higher in water willingness to pay, and thus are more insulated from the losses incurred by the scarcity of water. They may experience an increase in residential and industrial water prices, but these would be lower than what may occur in other models. The Salton Sea fares well in these models, due to the high regional welfare produced by the regional tourist economy. Thus, the social planner model provides a sustainable allocation for the Salton Sea while shielding urban centers from major water cutbacks yet severely damaging the agricultural sector in the region.

The simulations that operate on providing stakeholders with water in proportion to their existing usage and their claims produce a lower regional welfare than with the social planer model. Due to the fact that agricultural water uses already account for the majority of water use within the region, these models protect the ag producer interests by affording them the rights to the same proportion of water as supplies dwindle. Urban water sectors would be greatly hindered from contributing to the regional welfare to the degree that they are able, considering the high consumer surplus they produce. Furthermore, residential and industrial water prices will increase to a higher degree, and the simulations involving deficits of 2,150,000 AF may result in urban water shortages and drastically increased prices. The low quantity of water currently dedicated towards the Salton Sea does not allow it to be afforded a sustainable allocation. Yet by developing a model that explicitly supports the interests of maintaining the ecosystem, we can project the regional welfare with ecological provisions. This value is higher than the regional welfare produced by a model using only existing uses and entitlements, although lower than the welfare produced in social planner models. The proportional allocation model therefore is beneficial to the interests of the agricultural sector and may result in major price increases or urban water, while proving unable to effectively provide water to the Salton Sea except for scenarios in which water is legally committed to the environment.

The results for the models in which the senior rights of the IID are considered immutable are the most damaging to the regional welfare. Simply reducing the total regional water use to 4,150,000 AF results in a situation in which the IID is allocated at minimum 65% of the region's water. Once we begin considering scenarios in which the bankruptcy is even greater, we see massive reductions in the regional welfare. If we consider a year in which California is only able to receive 3,400,000 acre feet of water, the IID will be entitled to over 76% of the regions water, drastically reducing the ability of other stakeholders to utilize water, because they would have to divide a mere 800,000 AF between two major agricultural sectors and millions of residents. In times of major drought when the bankruptcy reaches 2,000,0000 AF, the IID would be entitled to all of the water that the region receives from the Colorado River. This leads to a devastating situation for the agricultural sectors of both the CVWD and the SDCWA, as well as causing major water shortages in the urban sectors of the MWD, CVWD, and SDCWA.

At the lowest levels of scarcity, the constrained equal award model produces a level of welfare that is indistinguishable from that of the social planner approach at the lowest level of scarcity. As the level of scarcity increases, the welfare level resulting from the constrained equal award model reduces to a greater degree than that of the social planner approach, although it remains greater than that of any other allocation framework. This framework provides a near-optimal level of welfare while affording more water to agricultural districts, although they would still bear the greatest reduction in usage. Additionally, this method asks stakeholders with a lower historic use to make fewer reductions. This is because of the low historic water use of most districts in comparison to the high historic water use of the IID, which means that it is easier to meet the upper allocation cap of these districts under the constrained equal award framework.

Policy Implications

Regarding the valuations that favor urban sectors, our assumption for this tendency is that it arises due to urban users paying full market rate for water, whereas agricultural water is heavily subsidized. This inflates the willingness to pay higher prices for water, far above what the agricultural users pay. It should also be noted that the models that do not take into account the IID's status as a holder of senior water rights indicate that these are not conducive to the general welfare. The system as it stands produces inefficiencies.

Regardless of the status of the IID's present perfected rights, it is outside of the realm of possibility that they would accept such drastic deficits in their entitlement. This does not necessarily mean that they would never accept a reduction in their entitlement, as they have willingly reduced their water use in prior agreements. Additionally, the IID has its own interest in maintaining the Salton Sea, due to the air pollution hazards it poses within its jurisdiction. The IID fielded Salton Sea restoration as its primary objective during negotiations for the Lower Basin Drought Contingency Plan, having subsequently been written out of the deal due to an unwillingness to budge on this issue. What this means is that it is not politically infeasible to convince the IID to follow a bankruptcy allocation model that sacrifices a portion of its allotment to sustain the Salton Sea, as they may consider it to be in their best interests despite the loss of welfare from the agricultural industry.

It should be noted that while urban districts produce a greater regional consumer surplus than agricultural users, they also have the ability to mitigate the loss of water and acquire water from alternate sources. In particular, the MWD and the SDCWA have a robust portfolio of water sources with which to replace deallocated Colorado River water.

The MWD district may be able to mitigate the loss of water through its current efforts to move towards using desalinated water, providing alternative options to using Colorado River water. MWD is currently funding three seawater desalination projects that are projected to eventually provide 46,000 AF of water annually. Two of these projects are undergoing environmental review. This agency is also working with a group of agencies that are coordinating desalination efforts for seawater and groundwater through CalDesal. A secondary factor to consider is that since 1985 the total demand for water in MWD has remained relatively the same, which means that providing alternative sources of water will not simply be put towards satisfying additional demand but can instead alleviate the need for other water sources (MWD 2018).

The greatest assets available to the San Diego County Water Authority are its ability and will to diversify its water sources, which will alleviate the damages caused by the loss of a given amount of water allocation from the Colorado River water. By the year 2017, over 40,000 AF came from desalination plants, representing nine sources of the total water supply to the SDCWA. The authority is also making headway into recycling water and hopes that potable reuse water will come to represent 16 sources of all water supplies in SDCWA by the year 2035. Finally, they seek to make more efficient use of their local surface and groundwater capabilities, which compose eight of the 2017 supply sources but will potentially compose 15 of the San Diego County water supply sources by 2020.

Meanwhile the stakeholders in the eastern half of the region (CVWD and IID) lack access to the ocean, receive less rainfall, and lack the influence and capital to import water from other regions.

The Imperial Valley, one of the region's largest users, relies solely on surface water drawn from the Colorado River and has no alternative sources. In response to this, the IID has developed contingency plans in the event that the Colorado River provides insufficient water to satisfy their present perfected rights. To this end, the IID has built a robust series of programs and initiatives aimed at improving conservation practices and infrastructure to make better use of existing water supplies. The most prominent of these programs is the On-Farm Efficiency Program, in which the IID reimburses farmers $285 for each acre foot of water conserved. Thus far, this program has led to conservation of over 44,371 AF of water per year. The IID also has developed its own contingency plan to equitably distribute water when the IID water supplies are insufficient to meet the demands of all users (IID 2018).

The Coachella Valley similarly has no alternative sources of water, although it is unique in that while it cannot replace its water sources, it can replace the economic use of that water. Assuming that a loss in allocation will affect the agricultural industry negatively, it is possible for the Coachella Valley to mitigate this loss through strengthening its tourism sector.

It is due to these factors that an allocation scheme that favors the interests of the IID may be justified even without taking into account their senior rights. They have the least ability to either replace their water sources or rearrange their economic base in the event of deallocation of any of the major stakeholders. This should not be taken to mean that the regulator should allocate water to a stakeholder producing a low amount of welfare simply because of its inability to adapt to the change. It is merely something to consider when looking to predict the state of the region after these frameworks are implemented. It also raises questions as to whether the loss in consumer surplus can be recuperated, based on the characteristics of our stakeholders.

It is our recommendation that a proportional use allocation model is followed by the region, primarily out of concern for political feasibility and stakeholder adaptation ability. The ability of most stakeholders to manage the loss of water in comparison to the IID mitigates the suboptimal regional welfare that these models produce.

Conclusion

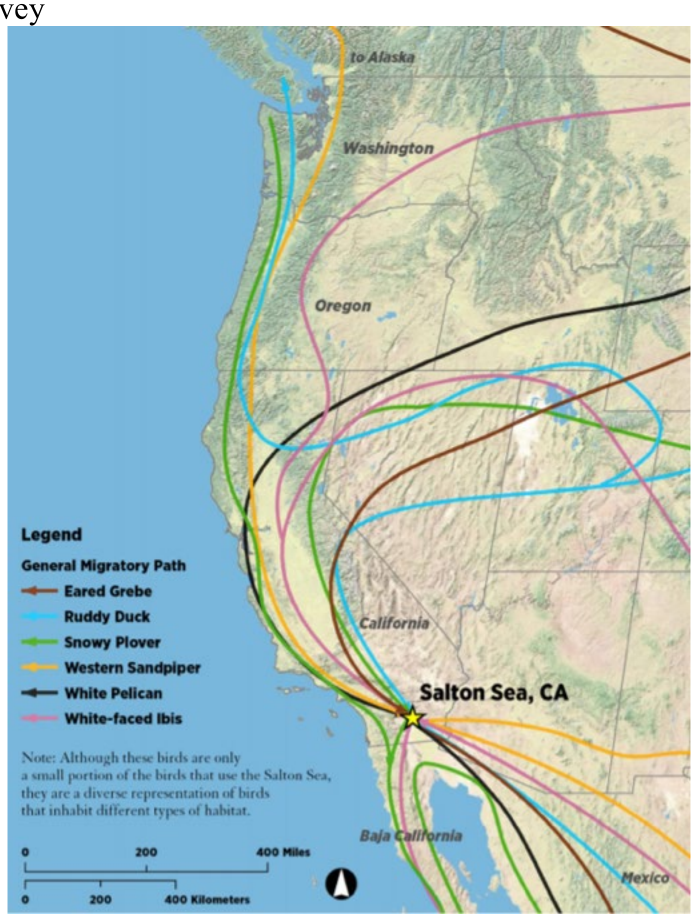
It is possible to minimize the loss in regional welfare as we move to establish a new normal with regard to water use in light of the decreasing flows of the Colorado River. This can be fulfilled by treating the water system as a bankrupt entity with a commitment of resources to stakeholders, which is in excess of what can be provided. As far as policy is concerned, the question of how to distribute these limited resources is answered by the benefits to the public derived from the new allocation. Loss must be minimized by determining the value of each unit of water for each stakeholder/sector. By calculating the consumer surplus for each stakeholder/sector provided by a given portion of the total regional water allocation, we can determine the welfare for the region by allocating water to a given stakeholder. It is through this procedure that we can establish the allocations that are most beneficial for the region as it transitions to a system in which less water is available.

Yet while it may be tempting to reduce it to a calculation of which sector the water provides the most benefit, we must still operate at least partly within the existing legal framework and stakeholder characteristics. Relating the value of water to a dollar amount helps us provide initial estimates on regional welfare losses, but multiple factors affect the region once our bankruptcy allocation framework is implemented. Urban sectors/stakeholders experience a much greater consumer surplus with the addition of water, yet these sectors/stakeholders are most equipped to deal with a scenario in which they receive less water. Conversely, agricultural users produce less regional welfare in terms of consumer surplus but are less able to adapt to a reduced allocation.

This study is also limited in that it does not take into account the social welfare costs associated with air quality and other health hazards stemming from the drying Salton Sea. In addition, we cannot predict the long-term regional welfare effects of the new status quo (resulting from each of the deficit allocations evaluated in this paper), which is dependent on the responses of stakeholders to the bankruptcy framework. These uncertainties do not negate the benefits of providing an assessment of the value of water, and using these values to provide predictions on the future welfare of the region has allowed us to minimize the loss expected by reducing our usage of Colorado River water.

Appendix Figure 1: The Salton Sea region

Appendix Figure 2: Bird flight paths from the Salton Sea on the Pacific Flyway, Source: United States Geological Survey



Appendix: Deficit allocations under the social planner and bankruptcy allocations scenarios

Social Planner Allocation

What follows is the welfare produced by the social planner approach. Indicated are the percentages of the existing average available water to be allocated to each stakeholder and sector. Also included is the total acre feet of water to be allocated to each sector and the projected social welfare produced through this allocation (Appendix Tables 1-3).

Appendix Table 1: Social planner allocation under 250,000 AF deficit

Stakeholder	Water Allocation %	Water AF	Social Welfare ($)
IID	41.45	1,720,000	5,079,766
CVWD (AG)	7.95	330,000	2,116,725
CVWD (URB)	5.3	220,000	207,386,859
MWD	24.1	1,000,000	343,811,730
SDCWA (AG)	0.84	35,000	175,996,251
SDCWA (URB)	7.11	295,000	85,714,160
SS	13.25	550,000	571,805,918
Total	100	4,150,000	1,391,911,409

Appendix Table 2: Social planner allocation under 1,250,000 AF deficit

Stakeholder	Water Allocation %	Water AF	Social Welfare($)
IID	25.08	790,000	4,688,575
CVWD (AG)	10.48	330,000	2,116,725
CVWD (URB)	6.98	220,000	207,386,859
MWD	29.52	930,000	343,760,053
SDCWA (AG)	1.11	35,000	175,996,251
SDCWA (URB)	9.37	295,000	85,714,160
SS	17.46	550000	$571,805,918.00
Total	100	3,150,000	1,391,468,541

Appendix Table 3: Social planner approach allocation under 2,250,000 AF deficit

Stakeholder	Water Allocation %	Water AF	Social Welfare
IID	12.79	275,000	3,596,294
CVWD (AG)	5.47	117,500	1,926,396
CVWD (URB)	10.23	220,000	207,386,859
MWD	30.58	657,500	342,768,355
SDCWA (AG)	1.63	35,000	175,996,251

SDCWA (URB)	13.72	295,000	85,714,160
SS	25.58	550,000	571,805,918
Total	100	2,150,000	1,389,194,233

Proportional Reduction and Constrained Equal Award Bankruptcy Allocations

The following three tables indicate the final water allocation for each stakeholder, proportional to their established entitlements, proportional to their existing use, and proportional to entitlements but with the provision of a long-term sustainable allocation for the Salton Sea. These three simulations have been completed under three water-scarcity regimes for a total of nine simulations (Tables 4-6).

Appendix Table 4: Proportional allocation under 250,000 AF deficit

Proportional Allocation Based on Actual Use			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	58.07	2,410,000	5,188,567
CVWD (AG)	8.98	372,500	2,116,725
CVWD (URB)	2.95	122,500	201,015,234
MWD	22.29	925,000	343,755,280
SDCWA (AG)	1.63	67,500	179,095,969
SDCWA (URB)	6.08	252,500	85,537,535
SS	-	-	-
Total	100	4,150,000	816,709,310

Proportional Allocation Based on Claims			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	57.23	2,375,000	5,184,414
CVWD (AG)	7.47	310,000	2,110,855
CVWD (URB)	5.00	207,500	207,208,217
MWD	22.71	942,500	343,771,254
SDCWA (AG)	0.78	32,500	175,242,281

SDCWA (URB)	6.81	282,500	85,675,466
SS	-	-	-
Total	100	4,150,000	819,192,487

Proportional Allocation With Salton Sea Provision Based on Claims			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	51.51	2,137,500	5,153,073
CVWD (AG)	6.75	280,000	2,100,262
CVWD (URB)	4.46	185,000	206,709,303
MWD	20.42	847,500	343,652,901
SDCWA (AG)	0.72	30,000	174,264,589
SDCWA (URB)	6.14	255,000	85,552,268
SS	10	415,000	431,453,556
Total	100	4,150,000	1,248,885,952

Proportional Allocation With IID Seniority Based on Claims			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	62.65	2,600,000	5,209,371
CVWD (AG)	6.57	272,500	2,097,200
CVWD (URB)	4.34	180,000	206,552,335
MWD	19.88	825,000	343,609,515
SDCWA (AG)	0.66	27,500	172,968,870
SDCWA (URB)	5.90	245,000	85,488,663
SS	-	-	-
Total	100	4,150,000	$815,925,955.00
		-	

Constrained Equal Award Allocation			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	41.45	1,720,000	5,079,766
CVWD (AG)	7.95	330,000	2,116,725
CVWD (URB)	5.30	220,000	207,386,859

MWD	24.10	1,000,000	343,811,730
SDCWA (AG)	0.84	35,000	175,996,251
SDCWA (URB)	7.11	295,000	85,714,160
SS	13.25	550,000	571,805,918
Total	100	4,150,000	1,391,911,409

Appendix Table 5: Proportional allocation under 1,250,000 AF deficit

Proportional Allocation Under Actual Use			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare ($)
IID	58.10	1,830,000	5,101,949
CVWD (AG)	8.97	282,500	2,101,241
CVWD (URB)	2.94	92,500	186,381,409
MWD	22.38	705,000	343,163,792
SDCWA (AG)	1.59	50,000	178,237,259
SDCWA (URB)	6.03	190,000	84,729,606
SS	-	-	-
Total	100	3,150,000	799,715,256

Proportional Allocation Under Claims			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	57.22	1,802,500	5,096,629
CVWD (AG)	7.46	235,000	2,078,551
CVWD (URB)	5.00	157,500	205,484,816
MWD	22.70	715,000	343,222,155
SDCWA (AG)	0.79	25,000	171,206,822
SDCWA (URB)	6.83	215,000	85,193,505
SS	-	-	-
Total	100	3,150,000	812,282,478

Proportional Allocation With Salton Sea Provision Under Claims

Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	51.51	1,622,500	5,057,888
CVWD (AG)	6.75	212,500	2,063,753
CVWD (URB)	4.44	140,000	203,932,348
MWD	20.48	645,000	342,662,205
SDCWA (AG)	0.71	22,500	168,735,152
SDCWA (URB)	6.11	192,500	84,790,189
SS	10	315,000	327,488,844
Total	100	3,150,000	1,134,730,378

Proportional Allocation With IID Seniority Under Claims			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	82.54	2,600,000	5,209,371
CVWD (AG)	3.10	97,500	1,973,228
CVWD (URB)	2.06	65,000	119,137,295
MWD	9.29	292,500	63,226,414
SDCWA (AG)	0.32	10,000	159,630,155
SDCWA (URB)	2.70	85,000	42,959,397
SS	-	-	-
Total	100	3,150,000	$392,135,861

Constrained Equal Award			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	27.38	862,500	4,745,387
CVWD (AG)	10.48	330,000	2,116,725
CVWD (URB)	6.98	220,000	207,386,859
MWD	27.46	865,000	343,681,633
SDCWA (AG)	1.03	32,500	175,996,251
SDCWA (URB)	9.21	290,000	85,699,678
SS	17.46	550,000	571,805,918
Total	100	3,150,000	1,391,432,451

Appendix Table 6: Proportional allocation under 2,250,000 AF deficit

Proportional Allocation Under Actual Use			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare ($)
IID	58.14	1,250,000	4,947,069
CVWD (AG)	8.95	192,500	2,047,289
CVWD (URB)	2.91	62,500	104,032,248
MWD	22.33	480,000	337,033,911
SDCWA (AG	1.63	35,000	175,996,251
SDCWA (URB)	6.05	130,000	80,492,646
SS	-	-	-
Total	100.0	2,150,000	704,549,415

Proportional Allocation Under Claims			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare ($)
IID	57.21	1,230,000	4,939,454
CVWD (AG)	7.44	160,000	2,010,454
CVWD (URB)	5	107,500	196,177,991
MWD	22.67	487,500	337,622,803
SDCWA (AG)	0.81	17,500	159,630,155
SDCWA (URB)	6.86	147,500	82,644,656
SS	-	-	-
Total	100	2,150,000	783,025,513

Proportional Allocation With Salton Sea Provision Under Claims			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare ($)
IID	51.51	1,107,500	4,887,532
CVWD (AG)	6.74	145,000	1,987,084
CVWD (URB)	4.53	97,500	190,498,629
MWD	20.47	440,000	332,545,331
SDCWA (AG)	0.70	15,000	150,684,685
SDCWA (URB)	6.05	130,000	80,492,646
SS	10.1	215,000	223,524,132
Total	100	2,150,000	984,620,039

Proportional Allocation With IID Seniority Under Claims			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	100	2,150,000	5,154,875
CVWD (AG)	0	0	0

CVWD (URB)	0	0	0
MWD	0	0	0
SDCWA (AG)	0	0	0
SDCWA (URB)	0	0	0
SS	0	0	0
Total	100	2,150,000	5,154,875

Constrained Equal Award			
Stakeholder	Water Allocation %	Allocation (AF)	Welfare
IID	19.77	425,000	4,156,081
CVWD (AG)	15.35	330,000	2,116,725
CVWD (URB)	10.23	220,000	207,386,859
MWD	19.88	427,500	330,487,515
SDCWA (AG)	1.51	32,500	175,242,281
SDCWA (URB)	13.49	290,000	85,699,678
SS	19.77	425,000	441,850,028
Total	100	2,150,000	1,246,939,167

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